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FLATHEAD BASIN FOREST PRACTICES
WATER QUALITY AND FISHERIES
COOPERATIVE PROGRAM

THE EFFECT OF TIMBER MANAGEMENT ON STREAM WATER QUALITY

BY F. RICHARD HAUER AND CHRISTOPHER O. BLUM

JUNE 1991

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About This Report

This report is one of ten individual studies conducted for the Flathead Basin Forest Practices/ Water Quality and Fisheries Cooperative Program. The Cooperative Program was administered by a Coordinating Team representing the Montana Department of State Lands Forestry Division, the Flathead National Forest, Plum Creek Timber Company, L.P., the Montana Department of Fish, Wildlife and Parks, the Montana Department of Health and Environmental Sciences' Water Quality Bureau, the University of Montana, and the Flathead Basin Commission.

The Cooperative Program's specific objectives were (1) to document, evaluate, and monitor whether forest practices affect water quality and fisheries within the Flathead Basin, and (2) if detrimental impacts exist, to establish a process to utilize this information to develop criteria and administrative procedures for protecting water quality and fisheries.

The ten individual studies included the evaluation of: (1) specific practices at the site level, (2) accumulation of practices at the watershed level, (3) general stream conditions, (4) water quality variables relative to levels of management activity in small watersheds, (5) fish habitat and abundance relative to stream variables influenced by forest practices at the watershed level, (6) long-term changes in large-stream dynamics related to historical records of natural and man-related disturbances, and (7) changes in lake sediments relative to historical records of natural and man-related disturbances. A *Final Report* was developed which contains summaries of each of the studies, a set of summary conclusions and recommendations, and a formal response to the recommendations by the land management organizations which administered the Cooperative Program.

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COOPERATIVE PROGRAM

THE EFFECT OF TIMBER MANAGEMENT ON STREAM WATER QUALITY

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JUNE 1991

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FLATHEAD RIVER BASIN
WATER QUALITY, FISHERIES AND FORESTRY
COOPERATIVE

* *

MODULE C

THE EFFECT OF TIMBER MANAGEMENT ON STREAM WATER QUALITY

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INTRODUCTION

Land-use practices on federal, state and private forested lands are a major concern among resource managers throughout the western U.S. and Canada. In recent years there has been considerable public controversy regarding specific forest management practices and the potential impact of those activities on streams and lakes. These concerns are particularly acute in the Flathead River Basin where over 80% of the upper basin (i.e. above Flathead Lake) is in public or private forestlands. The Forest Plan (1985) of the Flathead National Forest was challenged throughout the late 1980's by conservation groups, who contended that it provided for too much harvest and insufficient conservation or protection of water resources. There was also intense debate concerning the clear-cutting of timber across large tracts of land, particularly by large private land holders. The 1989-1990 Biennial Report of the Flathead Basin Commission stated, " A continuing controversy in the basin is the relationship between logging (with its attendant road building) and increased water, sediment and nutrients in streams and lakes."

Studies elsewhere in mountainous regions of the U.S., both in eastern and western forests, have shown that fine inorganic sediment, as a non-point source pollutant, may increase in streams in association with forest harvest to the point of degrading the aquatic resources (Cordone and Kelly 1961, Iwamoto and others 1978, Golladay and others 1983). However, sedimentation into streams and the potential direct consequences on fish populations and habitat is not the only concern. Other factors important to stream ecosystem structure and function, such as nutrient loading (Webster and others 1983), recruitment of woody debris (Triska and Cromack 1980), carbon dynamics (Meyer and Tate 1983), algae production (Lowe and others 1986), riparian canopy (Golladay and others 1983, Lowe and others 1986) and macro-invertebrates (Hawkins and others 1982), may also be directly or indirectly affected by activities associated with timber management.

Aldo Leopold, one of the great conservationists and naturalists of our time, once observed that the different components of an ecosystem are inextricably linked and that as we affect one of those components, others too will be affected. Perhaps no where is this more true than in the consideration of land - water interactions. Land disturbances, whether they are natural or man-induced, will affect the attributes (i.e. physical, chemical and biological character) of the water resources within the disturbed watershed. Two fundamental questions then become; "At what level can society extract natural resources from a particular watershed without degrading that watershed to unacceptable levels?", and "What are those acceptable or unacceptable levels of degradation?"

The primary purpose of this study was to evaluate whether past forest management practices have had a measurable effect on stream-water quality. Based on this primary purpose, we established the following goals; 1) to evaluate various approaches and limnological techniques that would be useful in examining the effects of forest management practices on stream/water quality, 2) impliment the appropriate studies that would be short-term yet provide specific empirical data addressing the problem of forest practices effects and 3) establish a baseline from which a longer monitoring plan might be developed.

Watersheds are often very different in natural character. It is within this variability that the study of non-point sources and point sources of pollutants is constrained. It is also within this variability that the land manager must operate to effectively control impacts due to land management activities. For example, commonly third or fourth order neighboring watersheds in the Flathead Basin drain different geological formations and thus have very different concentrations of suspended particulate and dissolved materials (Hauer and Stanford 1982). These streams may have different recent geological histories and frequently have different histories of human activity. Consequently, the study approach to obtain meaningful, empirical data for comparison of watersheds was initially constrained by natural differences. Our approach in this study was to primarily focus our comparisons across a series of paired watersheds in which pairs of stream sites possessed similar natural variables, but represented very different levels of timber management.

Because stream ecosystems are so complex and the number of factors that interplay to make up those systems so numerous, we were forced to select a limited number of variables to investigate which are both ecologically important and which we believed would be responsive to land disturbances related to forest management. We investigated three levels of stream ecosystem components; 1) sediments and nutrients, 2) algae growth, and 3) macroinvertebrate community structure and trophic groups. Our approach was based on the following hypotheses:

Working Hypothesis A: Timber management activites result in an increased sediment load to streams, which in turn result in higher concentrations of organic and inorganic sediment in transport, particularly during spring runoff.

Null Hypothesis A: There is no significant difference in suspended sediment concentration between paired streams with different levels of timber harvest .

Working Hypothesis B: Timber management activities result in increased concentration of dissolved and particulate nutrients, particularly soluble reactive phosphorus (SRP), nitrate (NO_3), ammonia (NH_4), total phosphorus (TP) and total persulfate nitrogen (TPN).

Null Hypothesis B: There is no difference in nutrient concentration between paired streams with different levels of timber harvest .

Working Hypothesis C: Increased sediment and nutrient concentrations from increased timber management activites (i.e. from Hypotheses A and B) result in increased algae growth on the stream bottom.

Null Hypotheses C: There is no difference in concentration of algal growth between paired streams with different levels of timber harvest .

Working Hypothesis D: Increased suspended sediment concentrations associated with timber management (i.e. from Hypotheses A) result in a decrease in the diversity of macroinvertebrate fauna.

Null Hypothesis D: There is no difference in species diversity among the macroinvertebrate fauna between paired streams with different levels of timber harvest .

Working Hypothesis E: Increased algae production related to timber harvest (i.e from Hypothesis C) results in a trophic shift within the macroinvertebrate community from a natural assemblage to one dominated by grazers and filter-feeders.

Null Hypothesis E: There is no difference in trophic relations or community composition related to trophic groups among the macroinvertebrate fauna between paired streams with different levels of timber harvest .

Each of these components of the stream ecosystem were examined and statistically analyzed for significant differences between paired watersheds in which the level of timber management activity was the dominant independant variable.

METHODS

Study Sites

A total of 12 stream sites were selected for study (Table 1 and Fig. 1) from within the Upper Flathead River Basin, Flathead and Lake Counties, Montana. Stream sites were selected to represent a cross-section of locations, watershed geomorphology, stream order, level of management activity within the watershed, and comparative stream reach character (e.g. canopy cover, extent of woody debris) (Table 2).

Table 1. Stream and Water Quality Sampling Sites for Biological and Physiochemical Monitoring indicating level of management activity[1] above the study site.

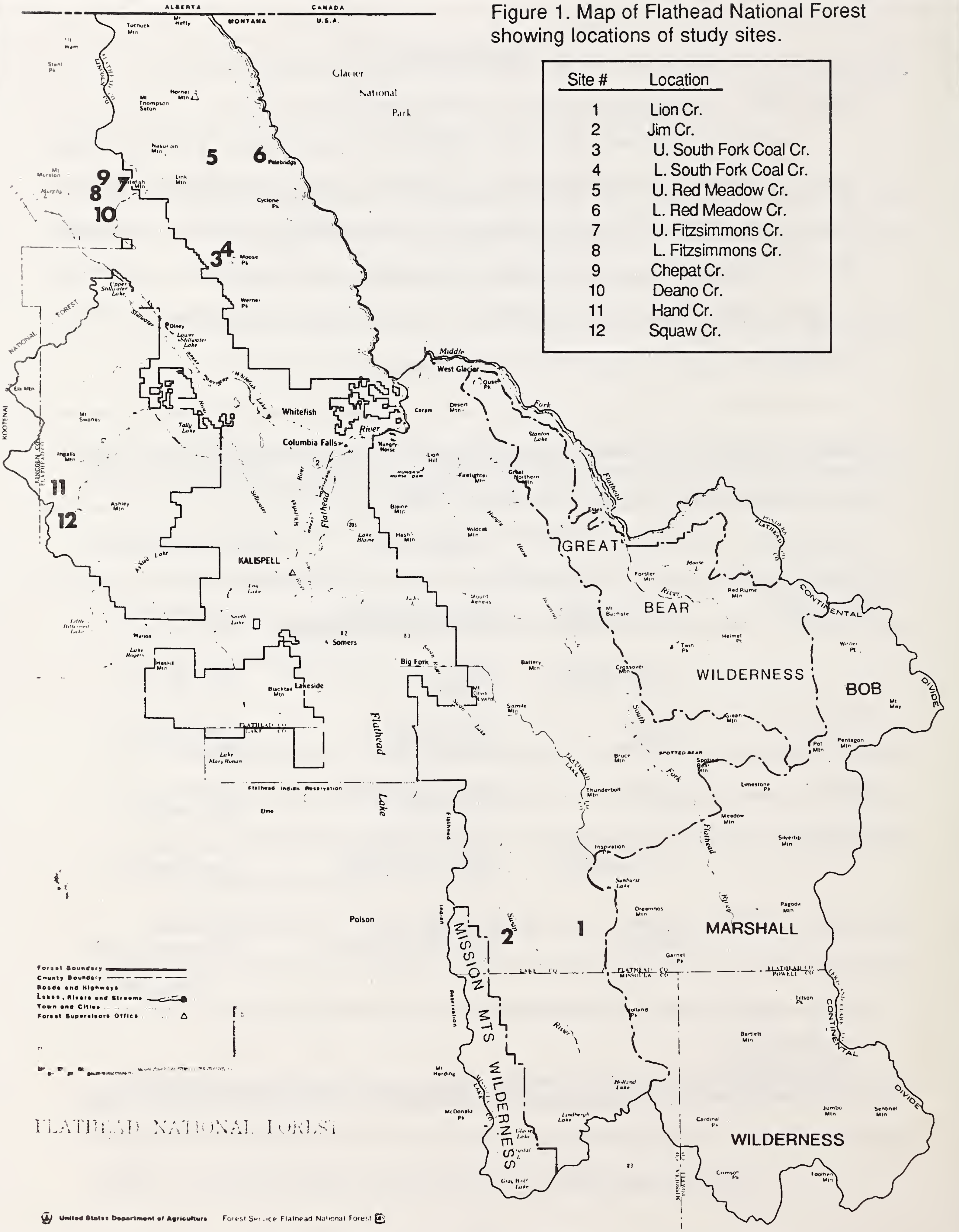
DRAINAGE	SITE	LOCATION	LEVEL OF ACTIVITY
North Fork	U. S. Fk. Coal	Above Rd 1686 Brdg.	Mod. Activity *
	L. S. Fk. Coal	2km downstrm Rd1686 Brdg	Mod. Activity **
	U. Red Meadow	RBF Site	High Activity **
	L. Red Meadow	RBF Site	High Activity **
Tally Lake	Hand	FNF/FBC Site	Low Activity *
	Squaw	FNF/FBC Site	High lActivity**
Swan	Lion	UMBS/FNF/FBC Site	No Activity *
	Jim	Rd 888 Brdg	High Activity *
Stillwater	U. Fitzsimmons	Above Upper Brdg	Low Activity **
	L. Fitzsimmons	Above Rd 900 Brdg	Low to Moderate Activity **
	Chepat	At Rd 900 Brdg	No Activity *
	Deano	Above Rd 900 Culvert	Scheduled Activity * but no activity during study *

* = Closed Canopy
** = Open Canopy

[1] Also considered in the designation of intensity of activity was the longitudinal stream distance between the activity and the sample site and the proximity of the activity to the stream corridor.

Figure 1. Map of Flathead National Forest showing locations of study sites.

Site #	Location
1	Lion Cr.
2	Jim Cr.
3	U. South Fork Coal Cr.
4	L. South Fork Coal Cr.
5	U. Red Meadow Cr.
6	L. Red Meadow Cr.
7	U. Fitzsimmons Cr.
8	L. Fitzsimmons Cr.
9	Chepat Cr.
10	Deano Cr.
11	Hand Cr.
12	Squaw Cr.



Lion Creek and Jim Creek in the Swan drainage were chosen as paired streams with highly different levels of timber management activity within their basins (Pair A, seeTable 2). Lion Creek, which drains the southern slope of Swan Peak, remains in nearly pristine condition above the sampling site with only a foot and stock trail leading to the upper portions of the basin. The Lion Creek site was characterized by large rubble substrata, large woody debris (e.g. fallen logs, tree limbs) and a well developed riparian forest. However, because of stream width the Lion Creek site had a relatively open canopy above the stream channel. Jim Creek, which originates from a series of small lakes along the east slope of the Mission Range, has had substantial timber harvest within the basin, including deviation from BMP guidelines and documented violation of Montana water quality standards (WQB pers. comm.). The Jim Creek site was located several km downstream of most timber harvest activity and was very similar in substrata and riparian character to Lion Creek.

Three watersheds with similar geomorphology draining the Whitefish Range were selected; Red Meadow Creek, South Fork of Coal Creek, and Fitzsimmons Creek. Two sample sites were located on each of these three streams; an upper and lower site, thus forming paired study sites B and C (Table 2).

The Upper Red Meadow Creek site was located ~ 5km downstream of its headwaters along the Whitefish Range divide. There has been substantial harvest activity within the drainage basin above this site including extensive harvest within the Streamside Management Zone (SMZ); however, this site was located upstream of areas affected by the Red Bench Fire. Stream size in this reach was sufficient to provide for a substantially open canopy even where the riparian vegetation was unharvested. The Lower Red Meadow Creek site was located just upstream of the North Fork Road. This site was located 6 - 8 km downstream where the Red Bench

Table 2. Size and other important physical characteristics related to timber management within each watershed upstream of the study sites.

PAIR & STREAM STUDY SITE	TOT ACRES	TOT RD MI	RD ACRES	% ROADS	ACRES HARVESTED	% HARVEST
A. Lion	14349	0	0	0.0	0	0
A. Jim	8656	31.1	62	0.7	2150	24.8
B. U Fitzsimmons	5087	3			0	0
B. U. SFK Coal	8435	22.1	180	2.1	1141	13.5
B. U. Red Meadow	10631	7.22			1337	12.6
C. L. Fitzsimmons	7353	5.2			0	0
C. L. SFK Coal	8435	23.1	181	2.1	1180	13.8
C. L. Red Meadow	14518	18.3	82	0.6	2786	19.19
D. Hand	550	1.8	5	0.9	38	6.9
D. Squaw Trib.	1075	5.8	24	2.2	316	29.4
E. Chepat	1177	0	0	0.0	0	0
E. Deano	1001	0	0	0.0	0	0

Fire crossed the creek; therefore, this site also involved long-term effectes of the fire. The site was characterized by a large rubble substrata and an open canopy.

Two sample sites were located on the South Fork of Coal Creek ~ 3 and 4 km respectively, above the confluence of the South Fork with the mainstem of Coal Creek. Considerable harvest has occurred above the upper site, however the stream flows through a steep sloped canyon section with a well developed, mature riparian forest above this site. The upper site is characterized by large cobble and gravel substrata, large quantities of instream woody debris, and a closed canopy. The lower site on the South Fork of Coal Creek is located ~ 1 km downstream of the upper site, but within a 2 km long clearcut along the stream bank leaving the site with no riparian canopy. The stream in this section has less woody debris than the upper site; however, there is considerable beaver activity in the area with numerous beaver dams crossing the stream channel.

The Upper Fitzsimmons Creek site was located ~ 50m downstream of the confluence of the mainstem and the North Fork of Fitzsimmons Creek, but above the bridge crossing. The site is characterized by a large rubble substrata and a naturally open canopy. The Lower Fitzsimmons Creek site was located ~ 100m upstream of the Rd 900 bridge. The bottom substrata is composed of large cobble and boulders with rock outcrops. The riparian vegetation is well developed along the stream banks in this stream section. The primary activity within the basin upstream of this site is the presence of the forest service road that parallels the stream for ~ 5km to the upper sampling site.

Hand Creek and Squaw Creek were selected as paired streams (Pair D), both originating along the basin divide in the upper Logan Creek watershed. Both streams are characterized by cobble substrata and relatively stained waters draining high elevation meadows. The Hand Creek drainage above the sampling site has had the least activity of any of the streams with some timber harvest; while in contrast, the Squaw Creek drainage has had extensive timber harvest in response to a substantial mountain pine beetle epidemic during the early 1980's.

Two second order streams within the Stillwater River drainage were also selected for study, Deano and Chepat Creeks (Pair E). Deano Creek is a previously unnamed stream flowing from the west slope of Herrig Mountain. Deano Creek is characterized by cobble substrata, an extensive quantity of woody debris dominating the stream channel and a completely closed canopy. Chepat Creek is very similar in character to Deano Creek and drains the west facing watershed of Mount Young. It contained considerable woody debris and had a closed canopy. Timber harvest was scheduled to occur during the study period on Deano Creek, thus permitting analysis of harvest effects on lower order streams. However, these cutting unit activities were postponed during the study requiring changes in the originally proposed between-site comparisons.

Sampling

We collected water samples for analyses of nutrients and suspended sediment at each sample site on four occasions through the annual cycle, three times during spring runoff (rising limb, near peak, and falling limb of the runoff hydrograph) and once during base flow conditions of autumn. Mid-stream grab samples were stored as whole water samples for suspended sediments and analyses of total nutrient concentrations. A portion of the water collected was field-filtered for dissolved nutrients and stored on ice in the field and returned to the laboratory, where both filtered and unfiltered water for determination of nutrient concentration were frozen for later laboratory analysis. All laboratory analyses were performed in the Freshwater Research Laboratory at Flathead Lake Biological Station using standard laboratory techniques and quality control procedures of the laboratories EPA approved methods manual.

We used artificial substrata consisting of 20 - 15 x 15 cm unglazed clay tiles fastened to a 1 x 1.25 m frame constructed of 4 cm dia. PVC tubing to sample benthic algal growth at each sampling site. The clay tiles were washed and soaked for 48 hrs in 10% HCl prior to deployment to remove foreign material from the surface of the tiles and leach any nutrients that may provide enhanced algal production. We attached the tiles to the PVC frames and deployed the sampling devices at each sampling station in mid-June 1990. The frame and tiles were positioned in each stream at a depth of 15 - 25 cm and a current velocity of 25 - 50 cm/sec. Great care was taken to position each sampling device in as similar microhabitats as possible across sampling stations. The frame attachment of the sampling device also permitted repositioning of the tiles as stream discharge decreased throughout the summer months. Thus, tiles were maintained in as nearly uniform microhabitats as possible. Tiles were removed for sampling purposes after 2, 4, and 8 weeks. We carefully removed three to four tiles from the frame on each sampling date and scraped them clean with a single-edged razor. We then collected all surface material on each tile in a separate opaque bottle and stored the bottle on ice and then returned it to the laboratory refrigerator. The following day each sample was filtered onto a Gelman GE glass-fiber filter and stored in the dark within the laboratory ultra-cold freezer. Within the following 2 -3 weeks each frozen benthic algae sample was analyzed for ash free dry mass (AFDM) and Chlorophyll α content following standard laboratory procedures.

We collected benthic invertebrates at each sampling site during autumn 1989 using a modified kick-net procedure specifically designed for collecting zoobenthos from the large substrata, low productivity streams of the Flathead River Basin (Hauer and Stanford 1981). Three samples were taken at each site and preserved in 10% formalin solution. All individuals were sorted from each sample, enumerated, and identified to the lowest taxonomic level possible and stored in 70% ETOH. We then identified most taxa to the species level, particularly the mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddisflies (Trichoptera). We were limited to the family level of identification among these three insect orders only for those specimens that were in very early stages of larval development and could not be further identified. However, because of the taxonomic complexity of the true flies (Diptera), this order of aquatic insects was identified to family only.

After identification and enumeration we analyzed the macroinvertebrate data by employing two commonly used indices of community structure; species richness and Simpson's index. Species richness is a simple measure of the number of species collected at each site (in this case taxa since not all groups were identified to species), while Simpson's index is a measure of equitability or the distribution of individuals occurring in each taxa. Taxa were also assigned to a trophic function group which classifies taxa based on their mode of feeding (Merritt and Cummins 1984) and analyzed for frequency of occurrence.

RESULTS AND DISCUSSION

Suspended Sediments and Nutrients

Analyses of suspended sediments and nutrients were compared to determine whether there were statistically significant differences in water chemistry variables between paired watersheds with different levels of timber management activity (see Table 2).

Total suspended solids concentrations tended to be higher among paired watershed streams flowing from high management activity basins (Fig. 2). This trend was very evident among the Lion/Jim Cr.; U. Fitzsimmons/U. South Fork Coal/U. Red Meadow; and L. Fitzsimmons/L. South Fork Coal/L. Red Meadow; watershed pairs. We did not observe this pattern in the Hand/Squaw Cr. pair; although we believe this to be due primarily to the relatively low gradient in these two streams and their comparatively low ability to transport materials because of insufficient stream power.

Stream chemistry values were highly variable both through time and between sites, even among watersheds with no up-stream activities. For example, NO_3 remained < 4 µg/L throughout all sampling dates at Deano Creek while achieving a maximum near 170 µg/L in Lion Creek during peak runnoff (Appendix A). This disparity in chemistry values between these streams can be largely attributed to the heterogeneity between watershed geology and stream order.

Table 3. Wilcoxon's signed-rank comparison of mean total suspended solids (TSS) three forms of nitrogen (NH_3, $NO_{2/3}$, and total persulfate nitrogen - TPN) and two forms of phosphorus (soluble reactive phosphorus - SRP, total phosphorus - TP) between no to low activity watershed sites paired to moderate to high activity watershed sites.

Nutrient Variable	Summary Statistic Low Activity < High Activity	Level of Signif.
TSS	$p = 0.043$	*
All nutrient variables combined	$p = 0.0053$	***
NH_3	$p = 0.715$	ns
$NO_{2/3}$	$p = 0.465$	ns
TPN	$p = 0.068$	*
SRP	$p = 0.273$	ns
TP	$p = 0.068$	*

ns = not significant

* = significant ($p < 0.10$)

** = highly significant ($p < 0.05$

*** = very highly significant ($p < 0.01$)

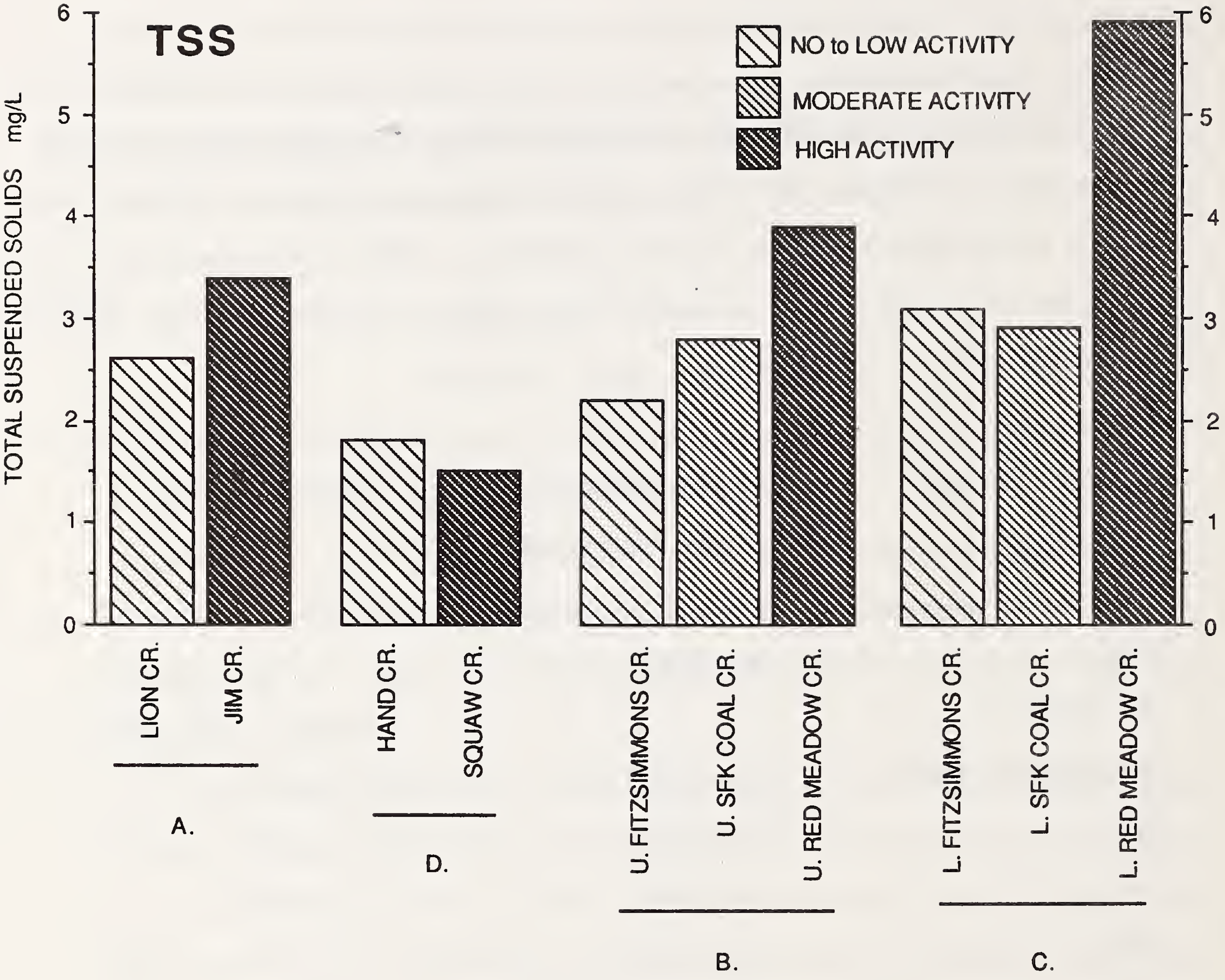


Figure 2. Annual maximum total suspended solids (TSS) at each of ten paired watershed sites. Site pairs appear as directly comparable sites with different levels of timber management activity in the watershed.

However, differences in nutrient concentrations between directly comparable streams may be due to differences in the intensity of basin management.

Comparison of annual maximum values between paired watershed sites (e.g. Lion/Jim Cr., U. Fitzsimmons Cr./U. South Fork Coal Cr./U. Red Meadow Creek, etc.) revealed that there was a significant difference in total phosphorus (TP; Fig. 3) and total persulfate nitrogen (TPN; Fig. 4) concentrations between drainages having differeng levels of management activity. In these pair-wise comparisons, the stream draining the watershed with the greater timber management activity had the higher total nutrient concentrations (Table 3). Differences were particularly distinct for combined annual maximums within a watershed when compared for total phosphorus (TP) and total persulfate nitrogen (TPN). In this cross-watershed comparison, TP and TPN concentrations were progressively higher between the low activity, moderate activity and high activity watersheds (refer to Table 1 for activity reference).

Stream Algae

Attached algae grew well on the tile substrates in the study streams. Several of the paired watersheds demonstrated dramatic differences in algae production (Fig. 4). For example, tiles from Squaw Creek, where trees have been extensively harvested, had nearly 10x higher concentration of chlorophyll α than did tiles from Hand Creek, which has experienced relatively little management activity above the sampling site. Similarly Jim Creek, which has had relatively high levels of management activity during the past decade, had significantly higher levels of algae growth than Lion Creek (ANOVA, $p < 0.05$), which has had no timber management activity above the sample site.

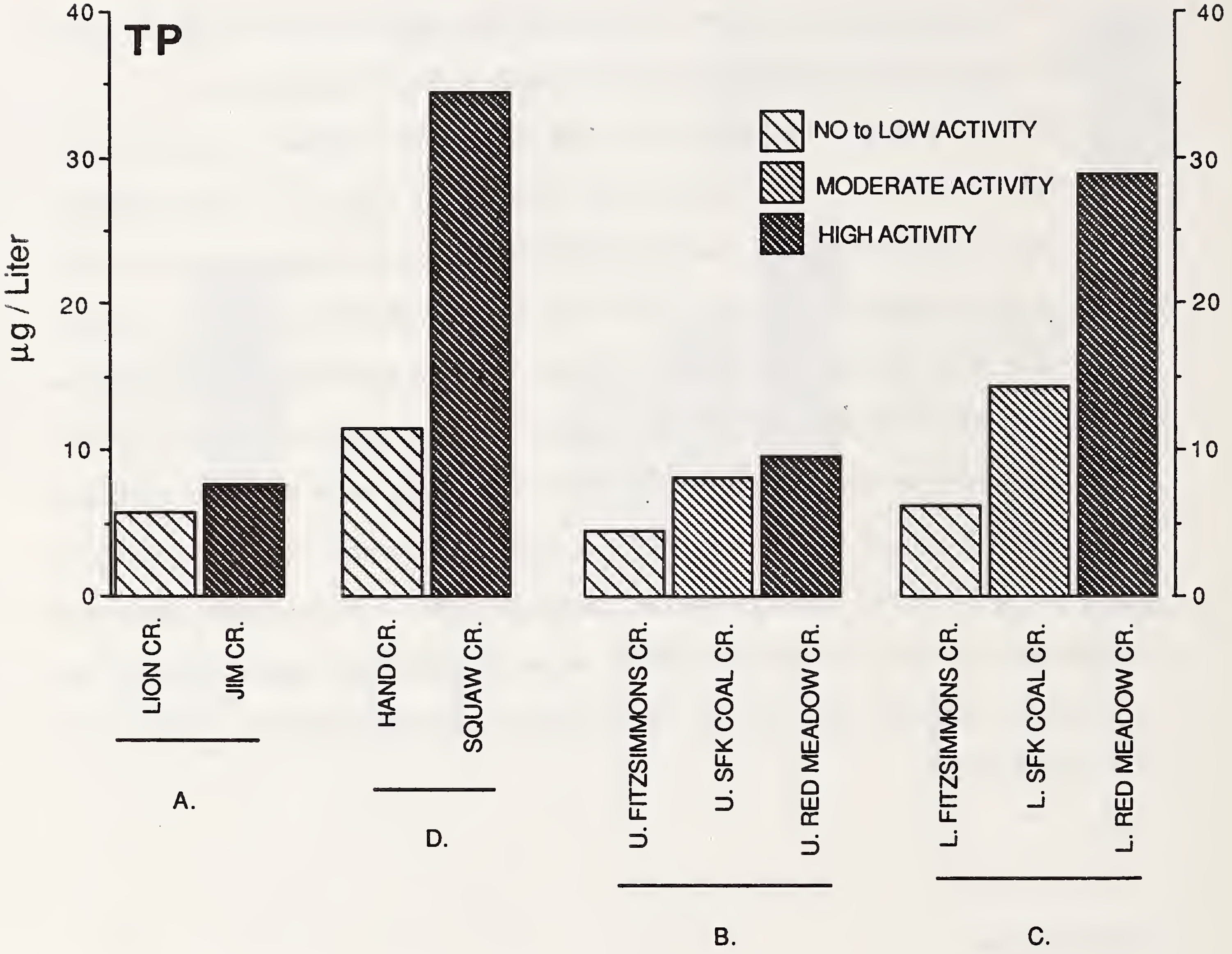


Figure 3. Annual maximum total phosphorus (TP) at each of ten paired watershed sites. Site pairs appear as directly comparable sites with different levels of timber management activity in the watershed.

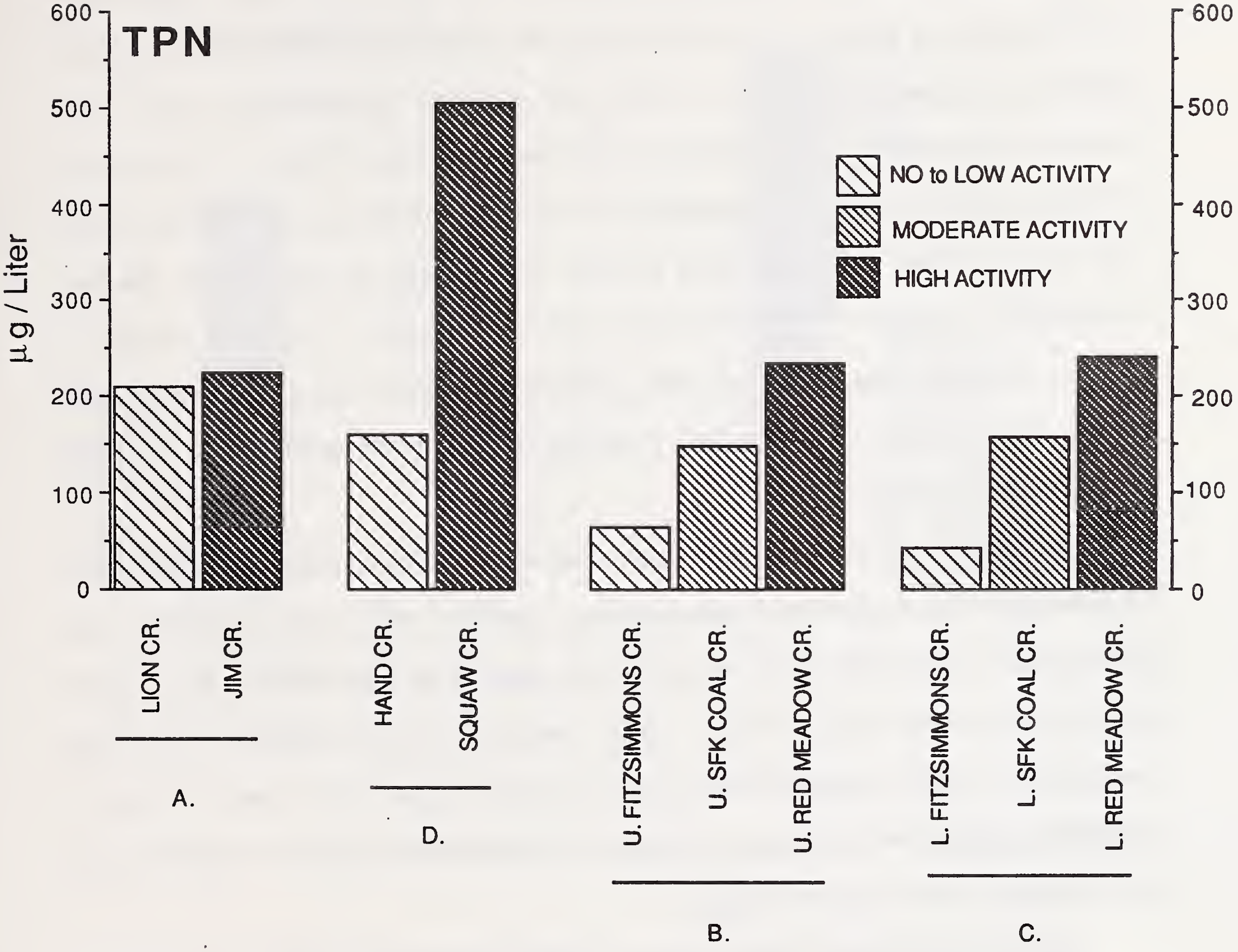


Figure 4. Annual maximum total persulfate nitrogen (TPN) at each of ten paired watershed sites. Site pairs appear as directly comparable sites with different levels of timber management activity in the watershed.

Results of the algae growth experiments in Fitzsimmons, South Fork of Coal and Red Meadow Creeks were more complicated than in the simple pair watershed comparisons described above for the Lion-Jim and Hand-Squaw creek pairs because of upstream - downstream comparisons, different levels of activity and different proximities of timber management activity to the study stream. In the upper Fitzsimmons Creek site, which had an open canopy with an undisturbed riparian, Chlorophyll α density remained <0.02 μg/cm^2 throughout the study period. In contrast, the lower Fitzsimmons Creek sampling site, which had a moderately open canopy, had a maximum Chlorophyll α density of 0.3 μg/cm^2, greater than a 10 fold increase over the upper site (Fig. 5).

The two South Fork of Coal Creek sites were similar in many variables, such as nutrient concentration and temperatures, owing to their close proximity. The algae density on tiles from both the upper and lower sites was relatively low. This is particularly noteworthy since the upper sections of the drainage have had considerable timber management activity (Table 2) and the lower site had a completely open canopy due to a ~15 year old streamside clearcut. However, both sites had low nutrient concentrations.

Upper Red Meadow Creek had the highest Chlorophyll α density measured during the study (0.564 μg/cm^2). This site also had high concentrations of nutrients; although, frequently the lower Red Meadow site nutrient concentrations were even higher. The lower maximum algal density observed at the lower Red Meadow Creek site can be largely attributed to accumulations of inorganic sediments on the surface of the tiles that tended to physically displace algal growth. These two observations, coupled with the extent of timber harvest that has occurred in this drainage, would strongly suggest that timber management activities are dramatically affecting stream algal production.

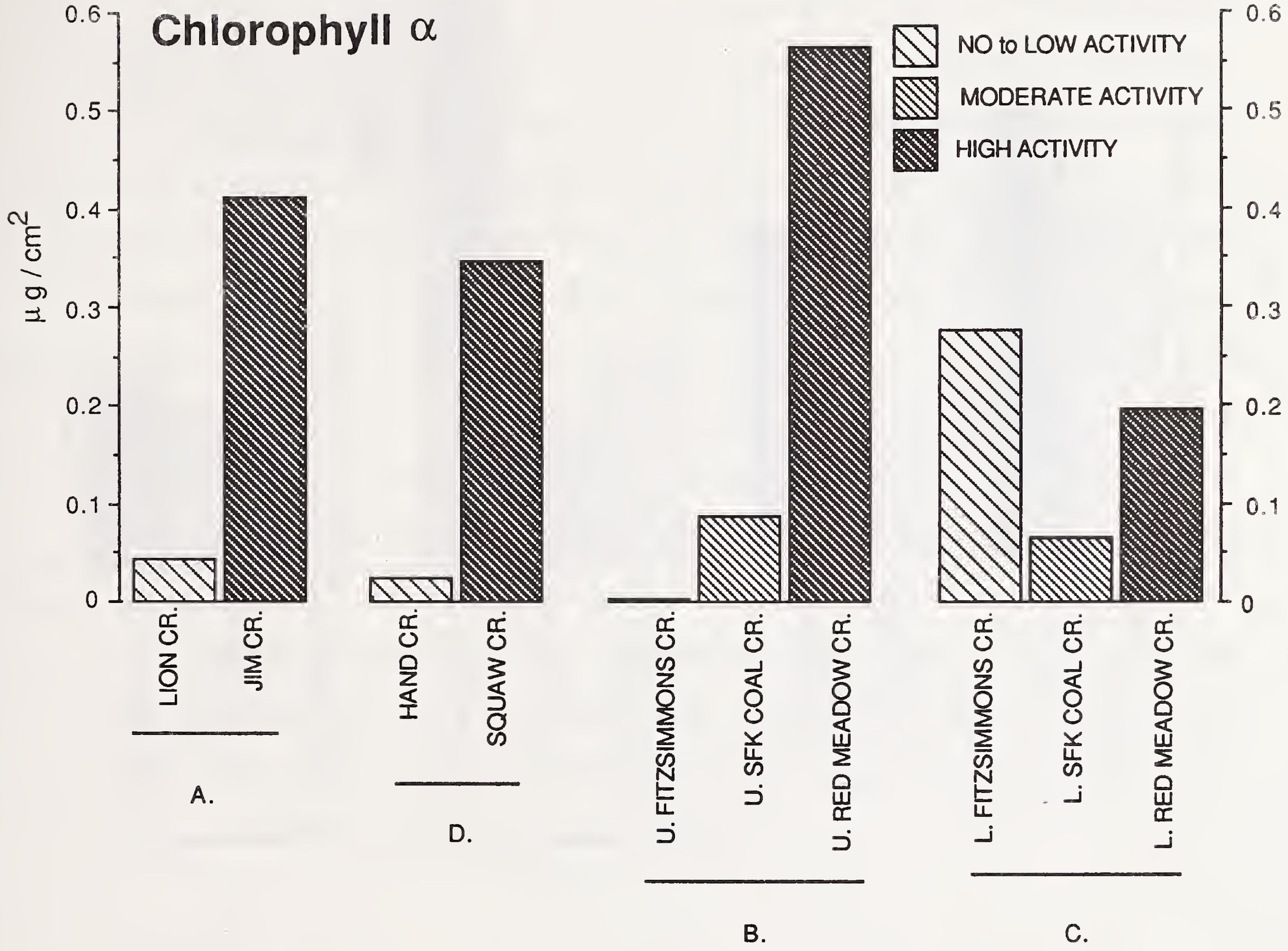


Figure 5. Annual maximum Chlorophyll α of algal growth on tile substrates at each of ten paired watershed sites. Site pairs appear as directly comparable sites with different levels of timber management activity in the watershed.

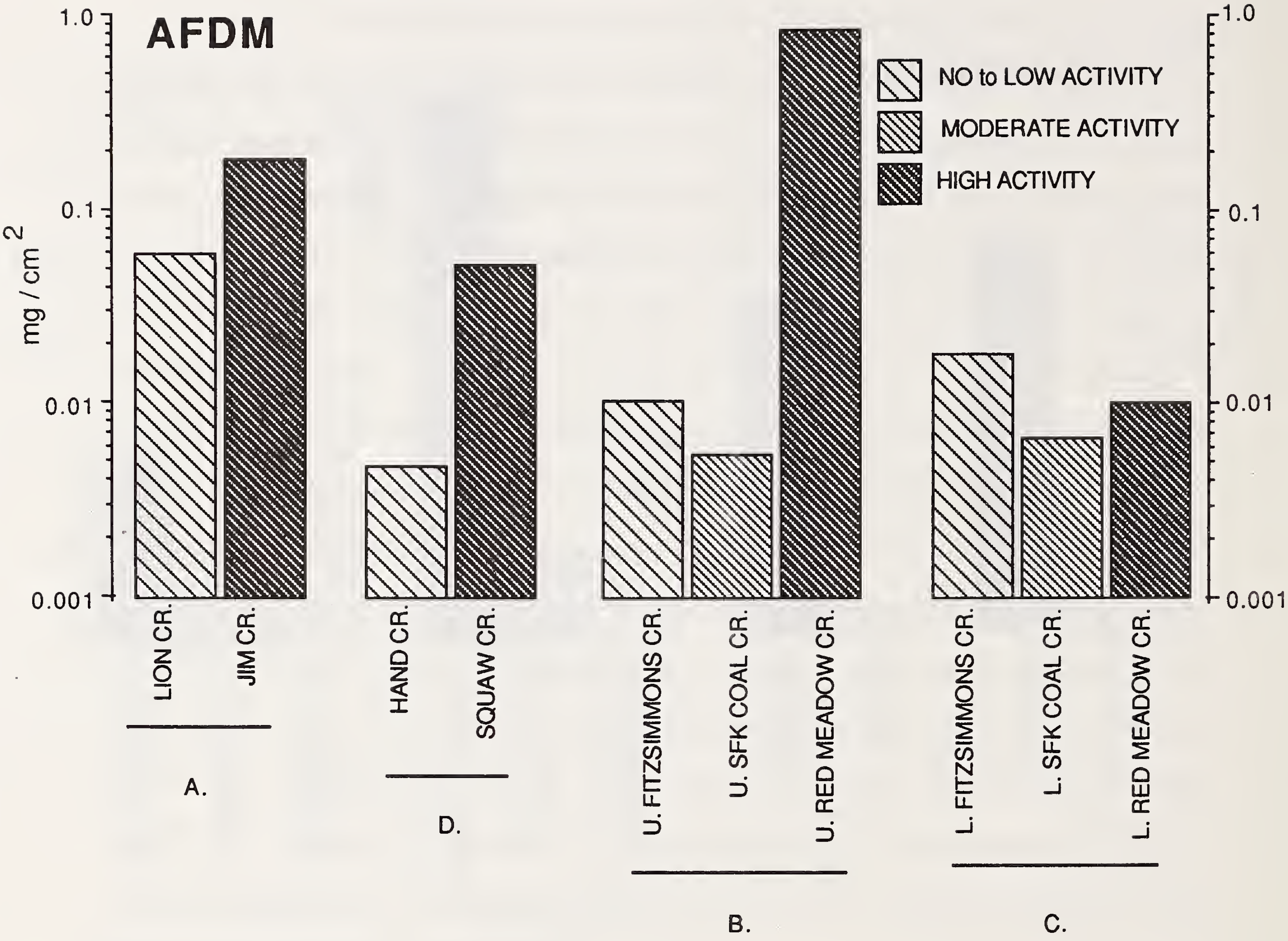


Figure 6. Annual maximum ash-free-dry-mass of algal growth on tile substrates at each of ten paired watershed sites. Site pairs appear as directly comparable sites with different levels of timber management activity in the watershed.

Based on these data (Fig 5), a general pattern emerges of increasing algal growth associated with increasing levels of watershed management activity. No activity and low activity watershed sites had very low algal production. Sites located within streams of moderate watershed activity had comparatively moderate levels of algal density, while the highest Chlorophyll α concentrations were measured within streams in high activity watersheds. An analysis of variance (ANOVA) of maximum Chlorophyll α data, in which sites falling into the three different activity levels were collectively compared, revealed that algal production was significantly less ($p < .05$) at low activity sites than high activity sites. This trend was not significant in regard to total organic matter accumulations (Fig. 6); however, the maximum value of AFDM was higher at high activity stream sites, but with a very high variance between sites.

Based on these data, which included a broad spectrum of stream types and stream orders, it appears that algal growth is greater in streams that flow from watersheds with high timber management activity than in streams that flow from drainages with low timber management activity.

Zoobenthos

A total of 67 taxa were identified from the 12 study sites (Appendix A). A detailed analysis of the zoobenthos data to distinguish patterns of zoobenthos response to possible effects of timber management was inconclusive. There was high variabilty of both species composition and frequency of occurance within stream sites, thus statistical significant differences between study sites were not determined. However, in spite of these limitations due to high replicate variabilty, several observations regarding the zoobenthic communities of the study streams were possible.

Of the 67 taxa collected, 32 taxa occurred at less than half of the study sites; with only 21 taxa occurring at 10 or more of the 12 sites. At the genus level of organization only *Baetis* sp., *Stenonema* sp., *Zapada* spp. and *Rhyacophila* spp. occurred at all sites. *Parapsyche elsis* occurred at 11 sites with *Arctopsyche grandis* occurring at the lower Red Meadow Creek site, the only site at which *P. elsis* was not found. The net-spinning caddisflies of the family Hydropsychidae occur abundantly throughout the Flathead Basin. Both *P. elsis* and *A. grandis* larvae typically occur in small, cool streams with the former usually appearing higher within a basin than the later. However, these species occupy the same ecological niche, thus the replacement of *P. elsis* by *A. grandis* is primarily a function of location along the altitudinal gradient of the stream rather than a response to harvest effects.

Examination of trophic functional groups revealed that among all study sites the collecter/gatherer (C/G) and shredder/detritivore (S/D) trophic categories were the most prevalent (Fig. 7a - b). In Deano and Chepat Creeks, collecter/gatherers and shredder/detritivores composed over 80% of the total organisms. The high frequency of collector/gatherers and shredder/detritivores would be expected for these small streams with no up-stream disturbance. Jim Creek was remarkably similar to Lion Creek in the percent frequency of collecter/gatherers, however Lion Creek had a much higher percent frequency of scrapers than did Jim Creek.

The six stream sites on the three Whitefish Range creeks were remarkably similar, having collecter/gatherers accounting for 55 - 60% of the zoobenthos. The exception to this was found at the upper Fitzsimmons Creek site, which had a high percent frequency of shredder/detritivores. This is indicative of a relatively high input of leaf material from riparian vegetation. Although the South Fork of Coal Creek had a more extensive canopy cover, that cover was composed primarily of a mature coniferous forest while the upper Fitzsimmons Creek site was dominated along its banks by alder. Thus, specific responses to site differences were observable, but those differences could not be attributed to specific management practices. This was readily observed in the comparison of Squaw and Hand Creeks, in which both

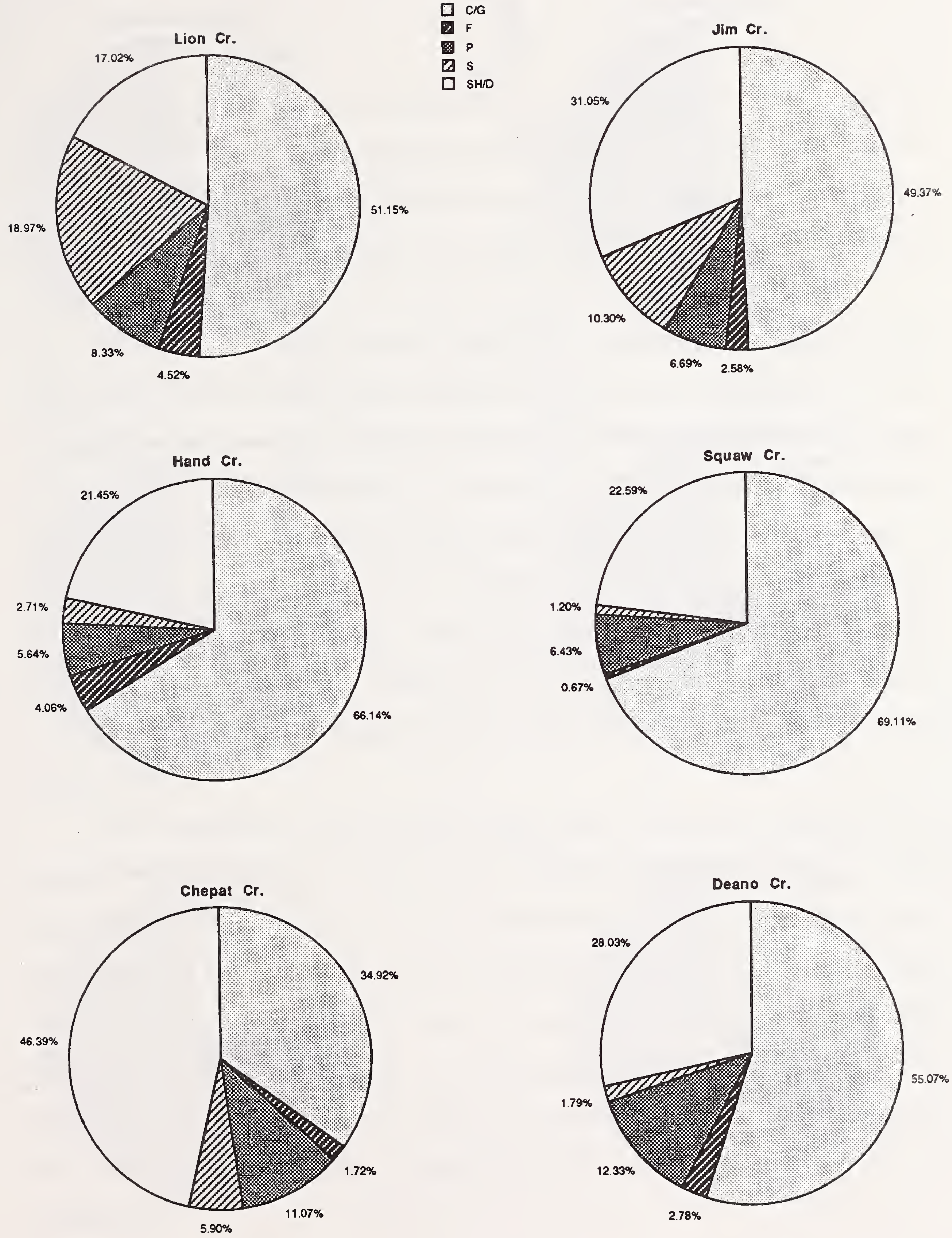


Figure 7a. Trophic relationships of macroinvertebrates from each study stream.
C/G = collector/gathers; F = filterers; P= predators; S = scrapers; SH/D = shredder/detritivores.

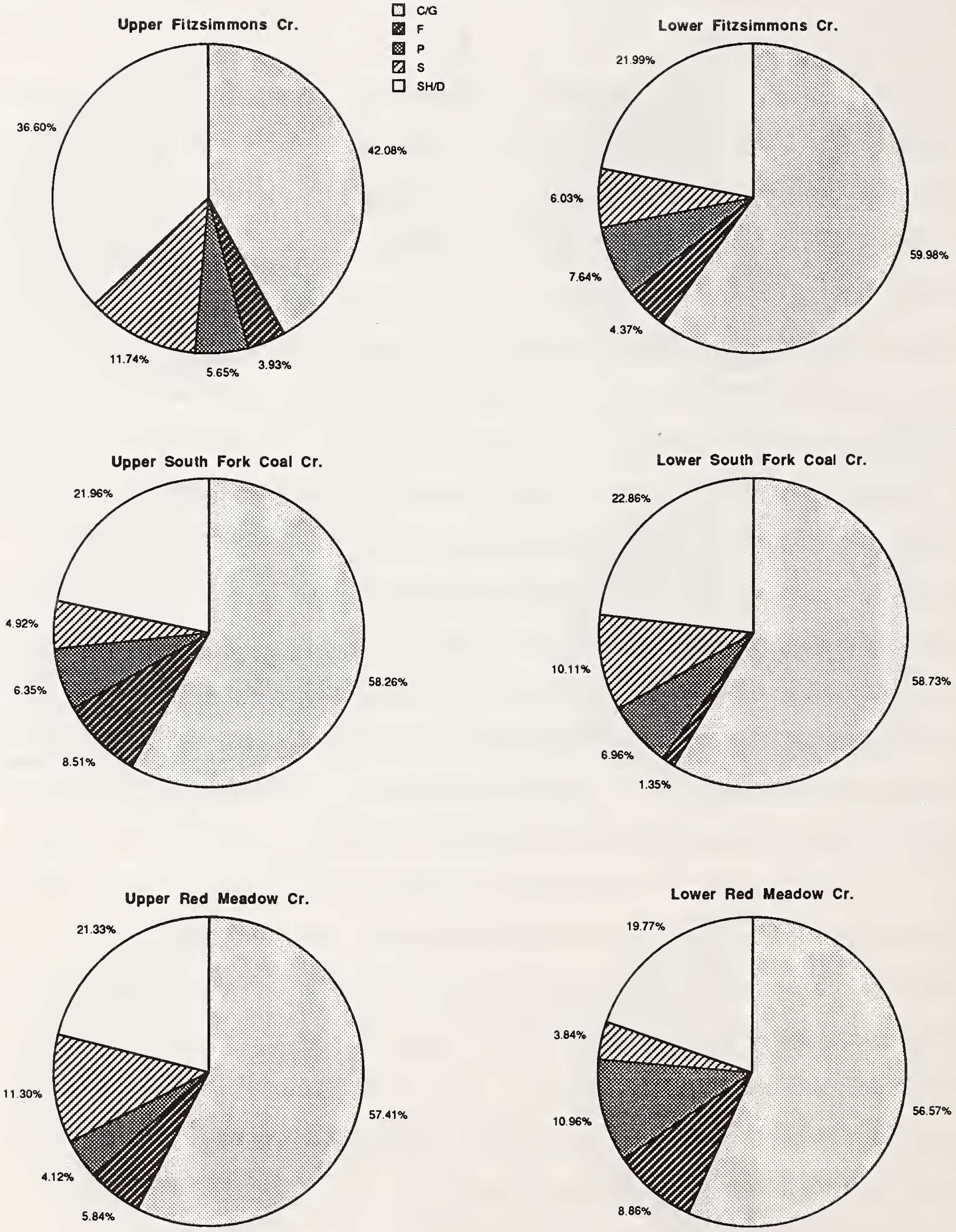


Figure 7b. Trophic relationships of macroinvertebrates from each study stream.
C/G = collector/gathers; F = filterers; P= predators; S = scrapers; SH/D = shredder/detritivores.

streams are dominated by collecter/gatherer species feeding on fine particulate material, primarily of detrital origin. The close similarity of these two streams in trophic function reinforces the fact that there were greater differences in zoobenthos between stream types than what was observed between paired streams having different levels of harvest.

Measures of species richness (Fig. 8) and Simpson's index (Fig. 9), were also variable between sites. Non-parametric tests of paired comparative streams revealed that there was no significant relationship that could be specifically related to timber management; however, there was a weak relationship of increased species diversity among those streams that had timber management above the sampling site. Similar results were described by Hawkins and others (1982) in which streams with disturbances in the drainage had greater species diversity. This observation is also consistent with the intermediate disturbance hypothesis of Connell (1978) and its application to streams (Ward and Stanford 1982, Resh and others 1988).

The variability of the zoobenthos data, both in species composition and trophic relationships, reflects the complexity of stream ecosystems. There are many factors which affect the distribution and abundance of stream plants and animals. This study did not identify statistically significant differences between sites when comparing the simple treatment factor of low activity and high activity timber management within the respective watersheds. However, this does not mean that there are no timber management effects on zoobenthos; but rather, that this study did not reveal any statistically significant differences based on paired site comparisons.

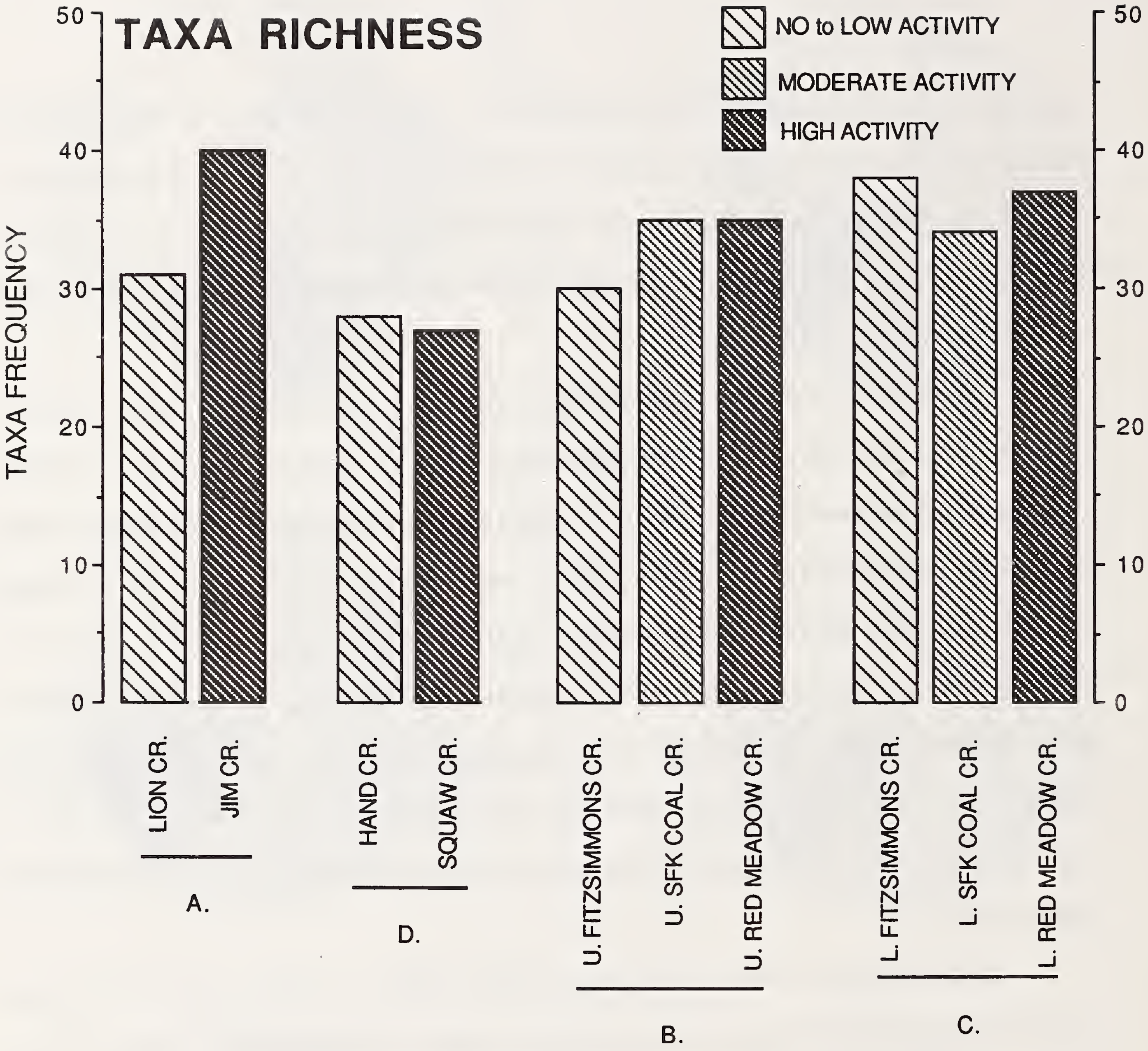


Figure 8. Autumnal taxa richness of riffle habitat macroinvertebrates at each of ten paired watershed sites. Site pairs appear as directly comparable sites with different levels of timber management activity in the watershed.

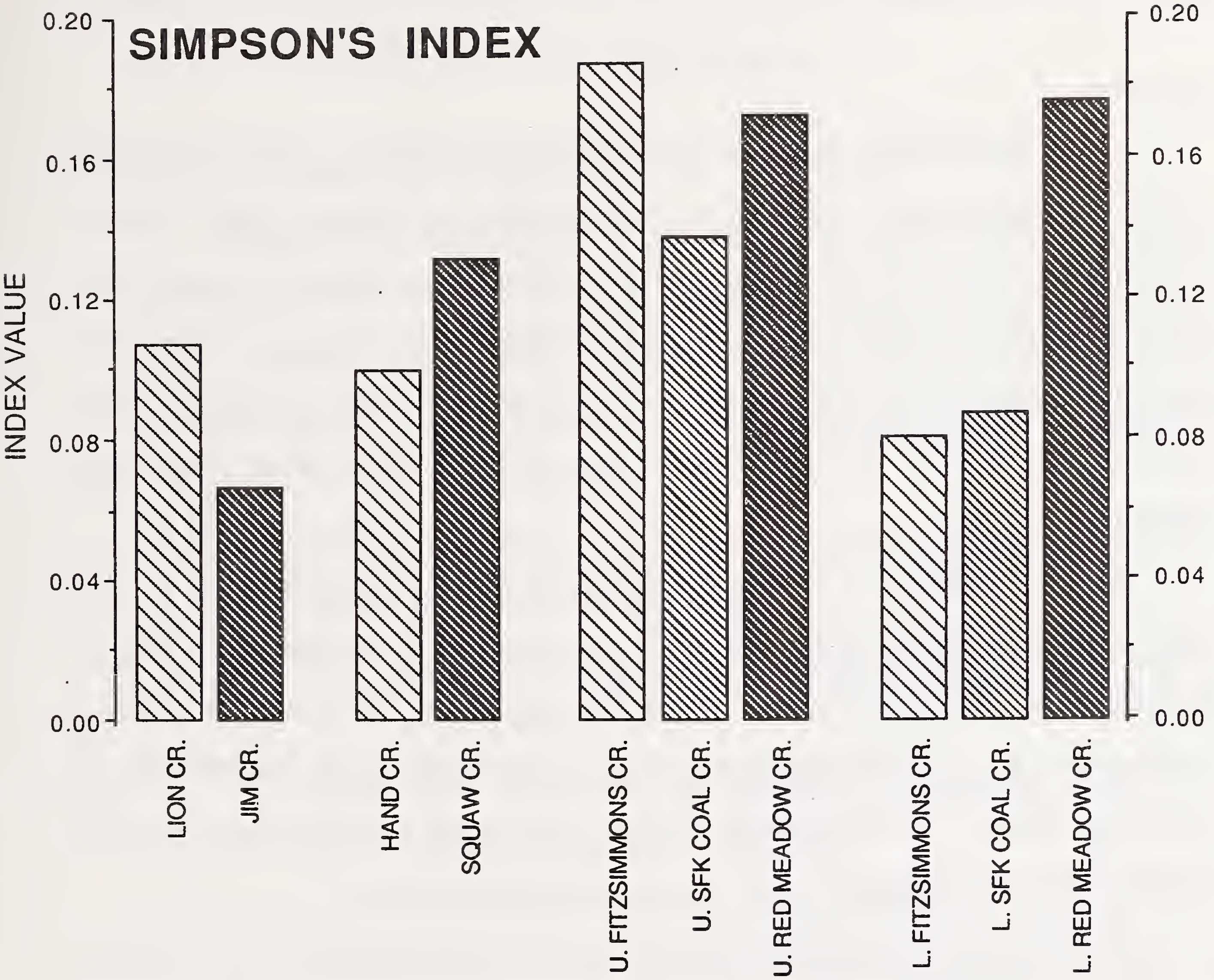


Figure 9. Simpson's index of macroinvertebrates during autumn in riffle habitats at each of ten paired watershed sites. Site pairs appear as directly comparable sites with different levels of timber management activity in the watershed.

SUMMARY, CONCLUSIONS and RECOMMENDATIONS

Summary

1). An experimental design of stream sites was chosen for study of the effects of timber management activity on the water quality of Flathead Basin streams. Stream sites were chosen to represent a broad cross-section of stream and watershed types; from very small streams to large creeks, from no to high timber harvest activities in the watershed, and from widely different geologies (Swan drainage, North Fork drainage, Upper Stillwater drainage, Upper Tally Lake drainage).

2). Concentration of sediment in transport was closely associated with the slope of the watershed and the gradient of the stream at the sample site. However, comparison of annual maximum suspended sediment concentration between paired-stream study sites revealed that moderate and high activity watersheds had a general pattern of significantly higher suspended sediment concentration ($p<0.05$) than their respective no to low activity watershed site.

3). Nutrient concentrations, particularly N and P fractions of Total Phosphorus (TP) and Total Persulfate Nitrogen (TPN), were significantly higher ($p < 0.1$) among stream sites within high activity watersheds compared to streams from no or low activity watersheds.

4). Attached algae growth was measured at each sample site using artificial substrates for colonization of algae. The density of Chlorophyll α on substrates incubated in streams with high timber management activities in the watershed was significantly higher ($p < 0.05$) than in streams from no or low activity in the watershed.

5). No significant differences in invertebrate trophic relationships, taxa richness, or taxa equitability were observed between streams of differing watershed timber management activity; however, there was a general trend toward increased species richness associated with harvest activity.

Conclusions and Recommendations

Because the conclusions drawn from this research are best expressed holistically as they relate to the other empirical studies, most recommendations of this study appear in the CONCLUSIONS AND RECOMMENDATIONS SECTIONS in the summary document. However, the following points should be made here in the context of the cooperative studies:

1). Timber management activity has a quantifiable effect on stream water quality in several important areas:

   a) increased maximum suspended sediment concentration during spring run-off,

   b) increased mean annual concentration of algal growth nutrients (nitrogen and phosphorus), and

   c) increased maximum algal density on the stream bottom.

   These factors not only profoundly affect the ecology of the stream, but also that of downstream lakes.

2). Future monitoring of timber management effects on streams should concentrate on measurement of suspended sediment, nutrient concentrations (TP, SRP, TPN, $NO_{2/3}$, NH_3), and attached algal growth (Chlorophyll α density).

3). Monitoring of macroinvertebrates will be most useful when used to define the most severe of impacts that result in catastrophic degradation of the stream biota. General baseline data of invertebrates is therefore needed among streams at risk.

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Appendix A. Mean number of individuals of each taxa at each of the water quality cooperative study sites.

TAXA	DEANO	CHEPAT	JIM	LION	SQUAW	HAND	LSFCC	USFCC	LFC	UFC	LRMC	URMC
Amphipoda												
Gamaridae					2.7							
Coleoptera												
Heterlimnius corpulentus			45.3		3.3		2.7	8.7	1.3		125.3	34.7
					2.0							
Hydrophilidae												
Noteridae					0.7							
Collembola												
spring-tail	0.7								0.7			
Diptera												
Chironomidae	91.3	102.7	131.3	182.0	214.7	50.7	53.3	62.7	109.3	45.3	274.7	38.7
Empididae			32.0	6.0		2.7		9.3	4.0			2.7
Psychodidae *Pericoma* sp.			1.3				38.7	5.3	2.7		512.0	17.3
Simulidae	4.0	9.3	14.7	2.0	6.0	18.7		5.3		2.7	13.3	13.3
Tipulidae	6.7	3.3	24.0	18.0	2.0	2.7	16.0	8.0	12.0		45.3	9.3
Ephemeroptera												
Ameletus oregonensis					2.7							
Ameletus velox	3.3	6.7		1.0		17.3	1.3		5.3	2.7		
Baetis sp.	26.7	81.3	274.0	202.0	36.0	21.3	690.7	1085.3	1021.3	173.3	288.0	1028.7
Caudatella edmundsi			106.7									
Caudatella hystrix			173.3	4.0				1.3	2.7			1.3
Cinygma sp.					9.3						56.0	4.0
Drunella doddsi	2.7	2.7	13.3	27.0	0.7		21.3	54.7	29.3	61.3	45.3	80.0
Drunella spinifera	0.7		126.0		7.3	13.3	1.3	1.3	5.3	2.7	10.7	6.7
Epeorus longimanus	13.3	30.7	8.0	67.0		1.3	94.0	145.3	102.7	38.7		46.7
Ephemerella inermis	2.7		85.3		70.7	61.3		2.7		4.0	42.7	1.3
Leptophlebia sp.					2.7							
Paraleptophlebia heteronea			92.0		114.0		1.3				21.3	2.7
Paraleptophlebia vaciva	11.3	34.7		2.0		120.0					5.3	
Rhithrogena robusta	1.3	8.0	45.3	84.0			160.0	142.7	104.0	108.0	93.3	112.7
Stenonema sp.	32.0	13.3	9.3	34.0	28.0	18.7	290.7	230.7	169.3	134.7	34.7	290.7

Appendix A continued. Mean number of individuals of each taxa at each of the water quality cooperative study sites.

TAXA	DEANO	CHEPAT	JIM	LION	SQUAW	HAND	LSFCC	USFCC	LFC	UFC	LRMC	URMC
Gastropoda												
Planorbidae					2.7							
Megaloptera												
Sialis sp.					12.0							
Oligochaeta												
Oligochaete	2.7	0.7	233.3	98.0	8.0	24.0	176.0	205.3	4.0	6.7	26.7	242.7
Platyhelminthes												
Planaria	5.3	86.7	131.3	16.0		12.0	5.3	74.7	56.0	1.3	2.7	8.0
Plecoptera												
Capniidae	15.3	40.0					24.0	26.7	32.0	38.7	16.0	
Chloroperlidae	2.7	30.7	25.3	8.0		26.7	121.3	32.0	88.0	125.3	16.0	156.0
Doroneuria theordora		9.3						6.7	6.7	7.3	134.7	14.0
Hesperoperla pacificum					4.0							
Kogotus sp.	6.0		4.0	3.0				2.7				
Leuctridae		58.7	12.0	13.0		8.0	86.7	42.7	138.7	101.3	5.3	80.0
Megarcys watertoni	0.7	2.7	2.7	18.0		0.7	13.3	13.3	6.0	5.3	14.7	5.3
Nemouridae						2.7			52.0	34.7		
Perlodidae		8.0	2.7		1.3	13.3			6.7	8.7		8.0
Setvena bradleyi	20.0	6.0										
Skwala parallela	2.0										4.7	
Sweltsa sp.	3.3	9.3	25.3	7.0		4.7	52.0	36.0	40.7	6.7	77.3	28.0
Taenionema pacificum	1.3	33.3	40.0	183.0			205.3	84.0	117.3	74.7	44.0	217.3
Yoraperla brevis	28.7	34.7	16.0				2.7	31.3	8.0	18.7	2.7	1.3
Zapada cinctipes	2.0	5.3	122.7		67.3	5.3	4.0	2.7	5.3	1.3	261.3	9.3
Zapada columbiana	28.0	109.3	58.7	39.0	4.0	45.3	81.3	210.7	153.3	110.0	136.0	78.7

Appendix A continued. Mean number of individuals of each taxa at each of the water quality cooperative study sites.

TAXA	DEANO	CHEPAT	JIM	LION	SQUAW	HAND	LSFCC	USFCC	LFC	UFC	LRMC	URMC
Trichoptera												
Anagapetus sp.	0.7	8.0		2.0			1.3	2.7		2.7		
Arctopsyche grandis											126.7	
Brachycentrus sp.			12.0				1.3				13.3	
Dicosmoecus gilvipes									0.7			
Ecclisomyia sp.											0.7	
Glossosoma sp.			28.0									6.7
Homophylax sp.	2.0	4.0					1.3		6.7	2.7	2.7	1.3
Hydropsyche oslari						4.0					77.3	
Lepidostoma sp.		4.0			117.3							
Limnphilidae			1.3					2.7				
Micrasema sp.	2.7	6.7	21.3		134.7	92.0					10.7	
Moselyana sp.				1.0		8.0		4.0			8.0	
Neothrema sp.	0.7	4.0		2.0		2.7						
Parapsyche elsis	5.3	4.7	25.3	49.0		1.3	29.3	241.3	110.7	44.7		147.3
Polycentropus sp.					36.0							
Rhyacophila acropedes	0.7	8.0	14.7	1.0	1.3	6.7	10.0	5.3	7.3	5.3	30.0	2.7
Rhyacophila hyalinata	0.7		1.3				9.3	21.3	6.7			
Rhyacophila narvae	2.0	9.3	24.0	25.0			1.3		6.7	6.7		2.7
Rhyacophila vaccua	5.3	13.3	3.3	10.0		5.3	46.7	74.7	88.7	28.0	21.3	48.7
Rhyacophila valuma		2.7	4.0	6.0			8.0		14.7		2.7	1.3
Rhyacophila verrula	0.7	21.3	10.0	4.0			4.0	14.7	5.3			
Rhyacophila sp. alberta group			10.7	14.0			13.3					
Species Richness	36	35	40	31	27	28	34	35	38	30	37	35

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